08:29:17 OCA PAD INITIATION - PROJECT HEADER INFORMATION 05/10/95

Active

Project #: E-24-X82 Cost share #: Rev #: 0
Center # : 10/24-6-R8507-0A0 Center shr #: OCA file #:
Work type : RES
Contract#: AGR DTD 950504 Mod #: Document : AGR
Prime #: Contract entity: GTRC

Subprojects ? : N CFDA:
Main project #: PE #:

Project unit: ISYE Unit code: 02.010.124
Project director(s):
ALEXOPOULOS C ISYE (404)894-2361

Sponsor/division names: GA DEPT NATURAL RESOURCES /
Sponsor/division codes: 300 / 031

Award period: 941201 to 950930 (performance) 950930 (reports)

Sponsor amount	New this change	Total to date
Contract value	5,985.00	5,985.00
Funded	5,985.00	5,985.00
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: EVALUATION OF PROPOSALS FOR EMISSION INSPECTION STATIONS IN THE STATE OF GA

PROJECT ADMINISTRATION DATA

OCA contact: Brian J. Lindberg 894-4820

Sponsor technical contact	Sponsor issuing office
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Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): N
Defense priority rating : N/A N/A supplemental sheet
Equipment title vests with: Sponsor GIT
NONE PROPOSED OR ANTICIPATED.
Administrative comments -
INITIATION OF PROJECT E-24-X82.

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

U

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 12/04/95

Project No. E-24-X82

Center No. 10/24-6-R8507-0A0

Project Director ALEXOPOULOS C

School/Lab ISYE

Sponsor GA DEPT NATURAL RESOURCES/

Contract/Grant No. AGR DTD 950504

Contract Entity GTRC

Prime Contract No.

Title EVALUATION OF PROPOSALS FOR EMISSION INSPECTION STATIONS IN THE STATE OF

Effective Completion Date 950930 (Performance) 950930 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	Y	
Government Property Inventory & Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

NOTE: Final Patent Questionnaire sent to PDPI.

E- 24 - X82
#1

Evaluation of Proposals for Emission Inspection Stations in the State of Georgia

Final Report

Submitted to

Air Protection Branch
Environmental Protection Division
Georgia Department of Natural Resources
4244 International Parkway, Suite 120
Atlanta, GA 30354

by

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November 9, 1995

Contents

1 Introduction

The purpose of this report is the evaluation of proposals by ENVIROTEST SYSTEMS and MARTA TECHNOLOGIES, Inc. for the establishment and operation of I/M 240 inspection facilities. Specifically, I have used simulation techniques to obtain estimates of mean waiting times and quantiles of the waiting time distribution for vehicles under seven worst-case scenaria.

Formally, if X is the (random) waiting time of a vehicle during a specific day, the p-quantile of X is the value x_p such that

$$P(X \leq x_p) = p.$$

In other words, $100p\%$ of the vehicles will spend in queue at most x_p time units.

A facility is modeled as queueing system with multiple (4–7) identical testing teams, each serving its own queue of waiting vehicles. The following assumptions have been made:

(a) The arrival rates of vehicles account for vehicles returning for retesting.

(b) Vehicles arrive according to a non-homogeneous Poisson process. In simpler terms, the times between arrivals of vehicles are independent exponential random variables with a parameter that fluctuates during a day. The rate function of the arrival process has been estimated by using historical data and prior experience by the bidding companies. A non-homogeneous Poisson process can be simulated by using the *thinning* method of Lewis and Shedler (1979).

(c) The test times are independent discrete random variables taking values 5 minutes with probability 0.8 or 6 minutes with probability 0.2. This assumption is based on data provided by the two bidding companies as well as discussions with Tom Lyttle. I should mention that none of the two proposals contains a detailed empirical distribution of test times.

(d) Vehicles remain in their queues, i.e., they do not jump to shorter queues.

(e) A vehicle that fails the emission test cannot be retested immediately.

(f) Vehicles that are present in a facility at the end of the day are tested.

2 Analysis of Simulation Output

Under each of the seven scenaria, I run a simulation experiment consisting of 100 independent replications of a day's activities. The simulation experiments were conducted by using GPSS/H. Then I used the waiting times from the 100 and the statistical package SPLUS to compute the quantile estimates and the graphs of the empirical cumulative distribution functions (cdf's) depicted in Figures 1–7.

The estimates were produced as follows. The waiting times from each experiment were ranked in increasing order $X_{(1)} < X_{(2)} < \cdots < X_{(k)}$ and the p-quantile was estimated from

$$\hat{x}_p = \frac{1}{2}\left(X_{\lfloor kp \rfloor} + X_{\lfloor kp+1 \rfloor}\right).$$

The empirical cdf's were created by tabulating the observed waiting times in one-minute intervals.

3 Worst-Case Scenaria

In this section I describe the seven worst case scenaria, tabulate the estimates, and conclude with a brief discussion. The Figures 1–7 of the empirical cdf's in Section 6 are identically numbered with the respective scenaria.

Scenario 1: ENVIROTEST's busiest off-peak day The arrival rate function, over half-hour intervals, is listed in Figure 6–1 (page 6–4) of ENVIROTEST's proposal.

Scenario 2: ENVIROTEST's extreme peak day The arrival rate function is listed in Figure 6–2 (page 6–6) of ENVIROTEST's proposal.

Scenario 3: MARTA's extreme peak day I considered the Buford Highway facility with 5 lanes and the following hourly arrival rate function.

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Rate	34	49	64	70	68	64	62	61	60	58	40	8

It should be mentioned that this is a very extreme scenario as MARTA assumes that it tests roughly 250,000 more vehicles in a year than ENVIROTEST.

Scenario 4: ENVIROTEST's adjusted extreme peak day The arrival rate function below is based on 1.8 million vehicle population for the 1996 year.

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Rate	16	37	41	46	42	40	39	39	35	33	28	22

Scenario 5: MARTA's adjusted extreme peak day The arrival rate function below is also based on 1.8 million vehicle population for the 1996 year.

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Rate	31	44	58	64	63	58	58	57	55	50	37	7

Scenario 6: Scenario 5 with an additional lane This case was considered for sensitivity analysis purposes.

Scenario 7: ENVIROTEST's adjusted extreme peak 9-hour day The following arrival rate function below was obtained from the respective function for scenario 4.

Hour	1	2	3	4	5	6	7	8	9
Rate	44	49	54	50	47	46	46	42	40

4 Experimental Results

The experimental results are summarized in the following table. Column 2 contains the average observed waiting times.

		Quantiles		
Scenario	Mean	0.50	0.85	0.99
1	1.25	0.00	3.12	8.97
2	8.19	5.43	16.79	38.03
3	77.48	73.72	132.91	187.53
4	13.84	9.60	27.23	62.63
5	42.41	38.44	75.97	119.18
6	4.01	2.48	8.37	21.76
7	47.26	42.64	83.81	124.70

The estimates under the first scenario are lower than those listed in Figure 6–1 of ENVIROTEST's proposal. However, the estimates under scenario 2 are substantially larger than the estimates listed in Figure 6–2. For example compare the average waiting times of 8.19 and 5.348 respectively. These discrepancies may be due to the following reasons:

(a) The estimates provided by ENVIROTEST appear to have been obtained from a *single* run. In fact, several of my runs produced outputs similar to those listed in Figures 6–1 and 6–2.

(b) The non-homogeneous Poisson arrival process may have been simulated incorrectly by ENVIROTEST personnel. The method I used is mathematically precise and avoids potential problems resulting from a "naive" method for simulating a non-homogeneous Poisson process (see Law and Kelton 1991, pages 507–510). This naive method has a tendency to skip peak time periods.

Based on the estimates under the first two scenaria, I conclude that ENVIROTEST will meet the EPD specifications.

Scenaria 5 and 7 yield unacceptably large estimates because the mean arrival rate exceeds or is close to the mean service rate for several hours. Based on the output data, I cannot conclude that ENVIROTEST's design dominates MARTA's. The dramatic reduction of the estimates under scenario 6 indicates the potential of an additional line to reduce the waiting times below the EPD specifications during extreme peak days.

MARTA's Queueing Model

MARTA's proposal contains no results from simulation experiments. The queueing model in pages 1–34 to 1–36 is a steady-state model in that it estimates long-run performance measures. However, the real model is transient because an inspection center operates at most 12 hours a day. Also, it ignores waiting time quantiles and fluctuations in the arrival rates.

I believe that the model is the well-studied **M/M/K** model where the interarrival time distribution is exponential with rate A, the test time distribution is also exponential with rate S and K is the number of lanes. Under these assumptions, the equations in the middle of page 1–35 are wrong. The correct equations are

$$P(0) = \frac{1}{\sum_{n=0}^{K-1} \frac{1}{n!} \left(\frac{A}{S}\right)^n + \left(\frac{A}{S}\right)^K \frac{1}{K!} \left(\frac{KS}{KS-A}\right)}$$

and

$$W_Q = \frac{K-1}{S} + \frac{S\left(\frac{A}{S}\right)^K P(0)}{K!(S-A)^2}.$$

5 References

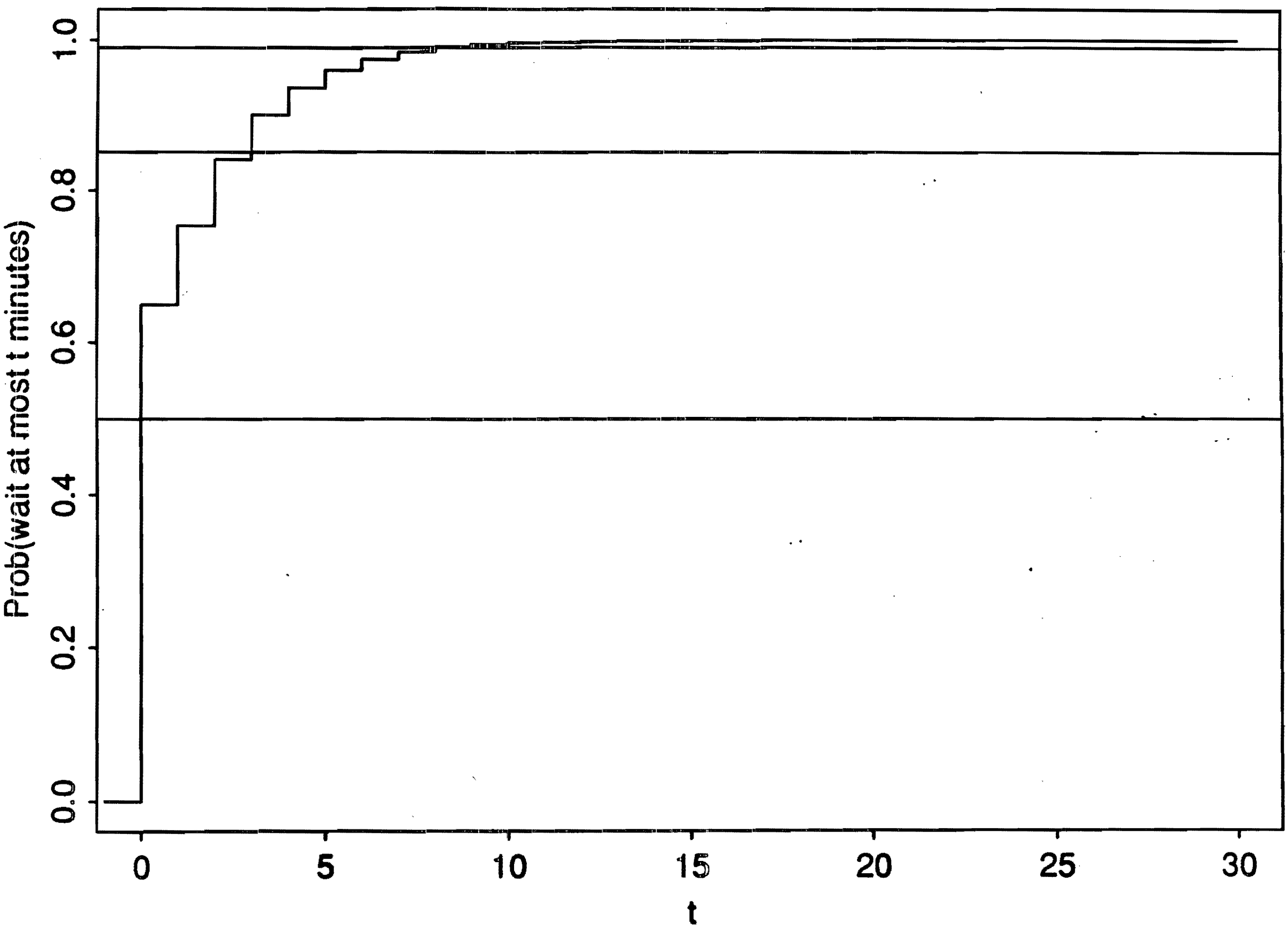
LAW, A. M. AND KELTON, W. D., *Simulation Modeling and Analysis*, 2d Ed. McGraw-Hill, New York, 1991.

LEWIS, P. A. W. AND SHEDLER, G. S., "Simulation of Nonhomogeneous Poisson Process by Thinning," *Naval Research Logistics Quarterly* **26**, 403–413, 1979.

6 Graphs of Empirical Distribution Functions

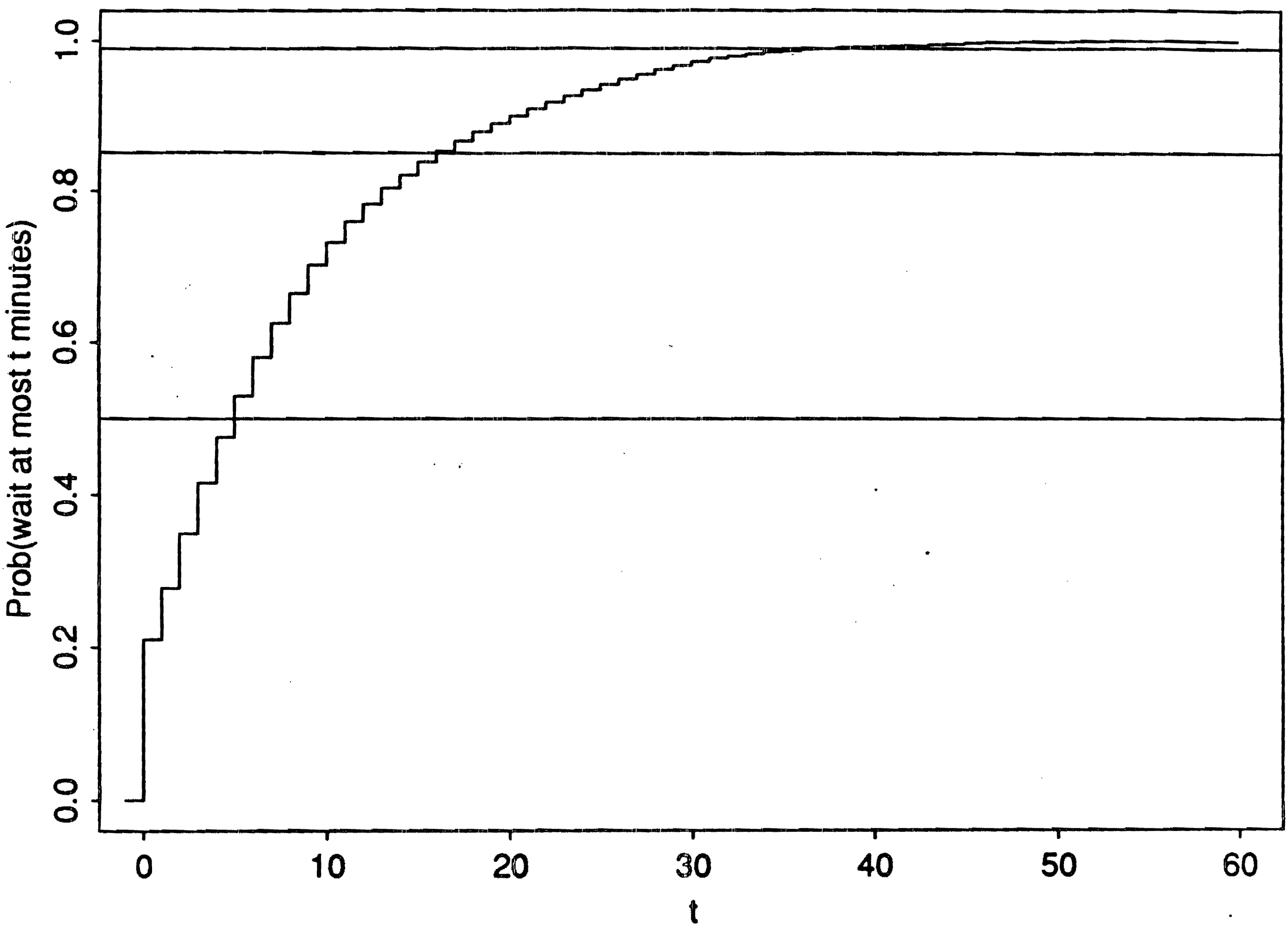
Scenario 1

FIGURE 1: Envirotest Busiest Off-Peak Day (Fig. 6-1)



Scenario 2

FIGURE 2: Envirotest Extreme Peak Day (Fig. 6-2)



Scenario 3

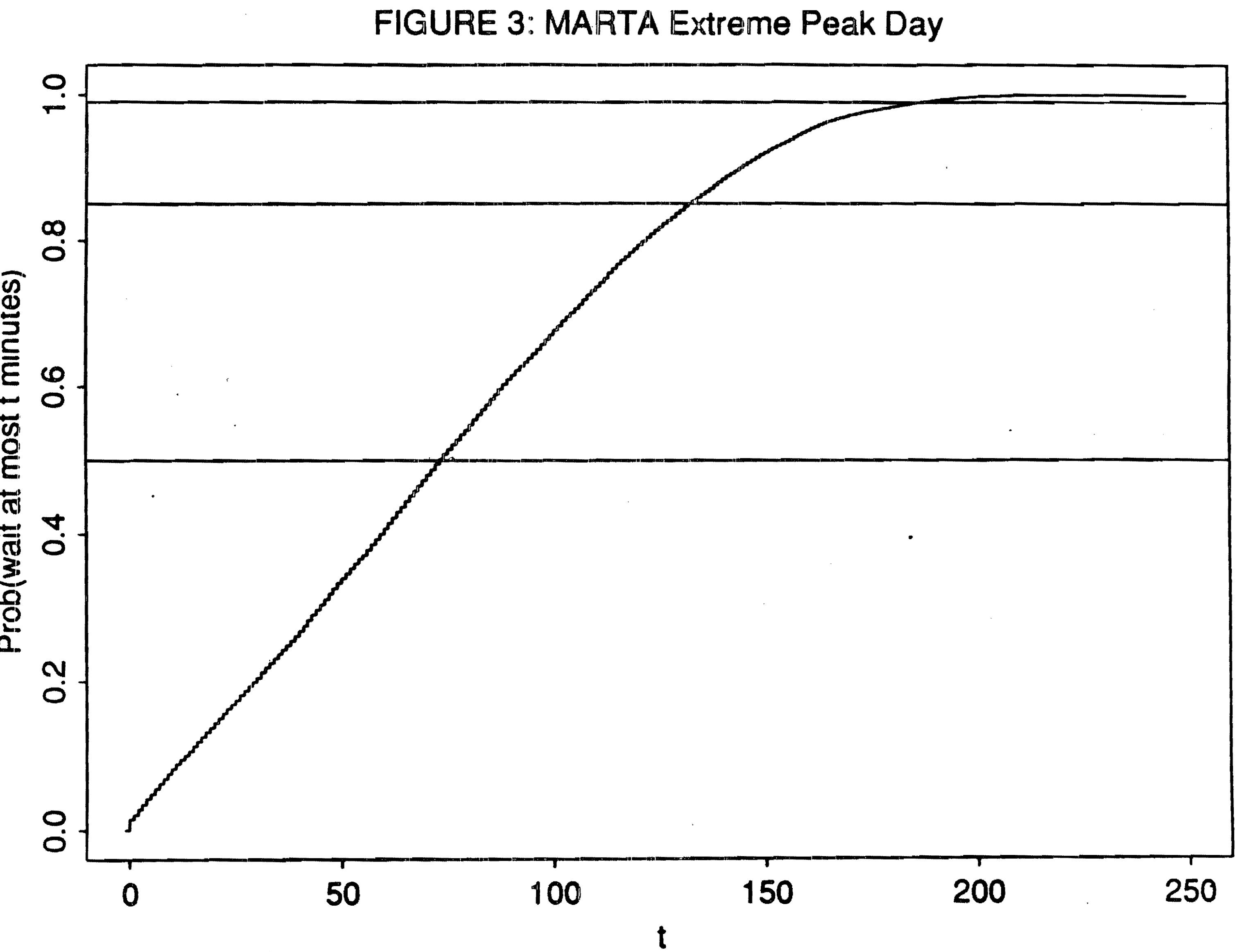
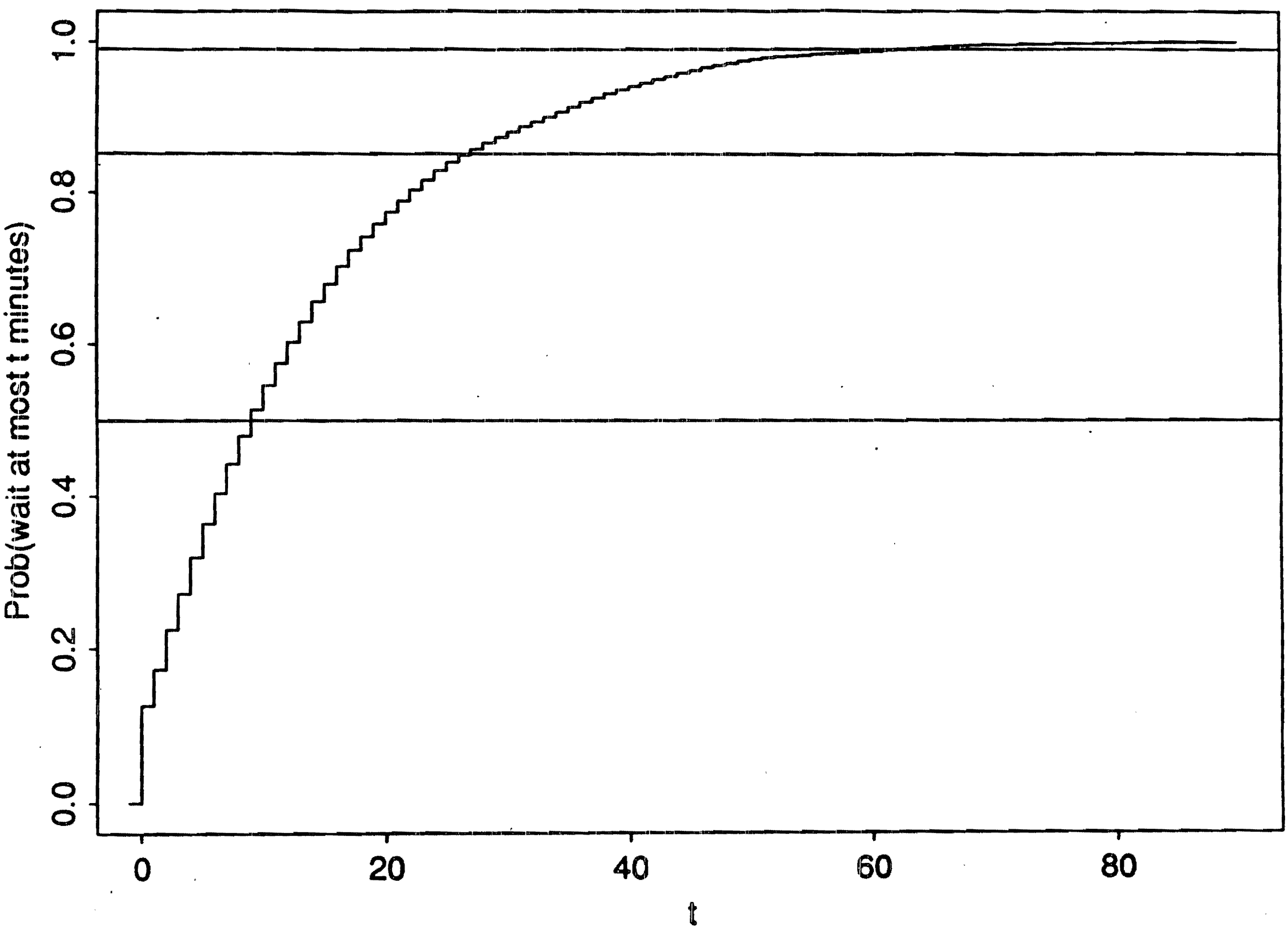


FIGURE 3: MARTA Extreme Peak Day
Prob(wait at most t minutes)
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200
250
t

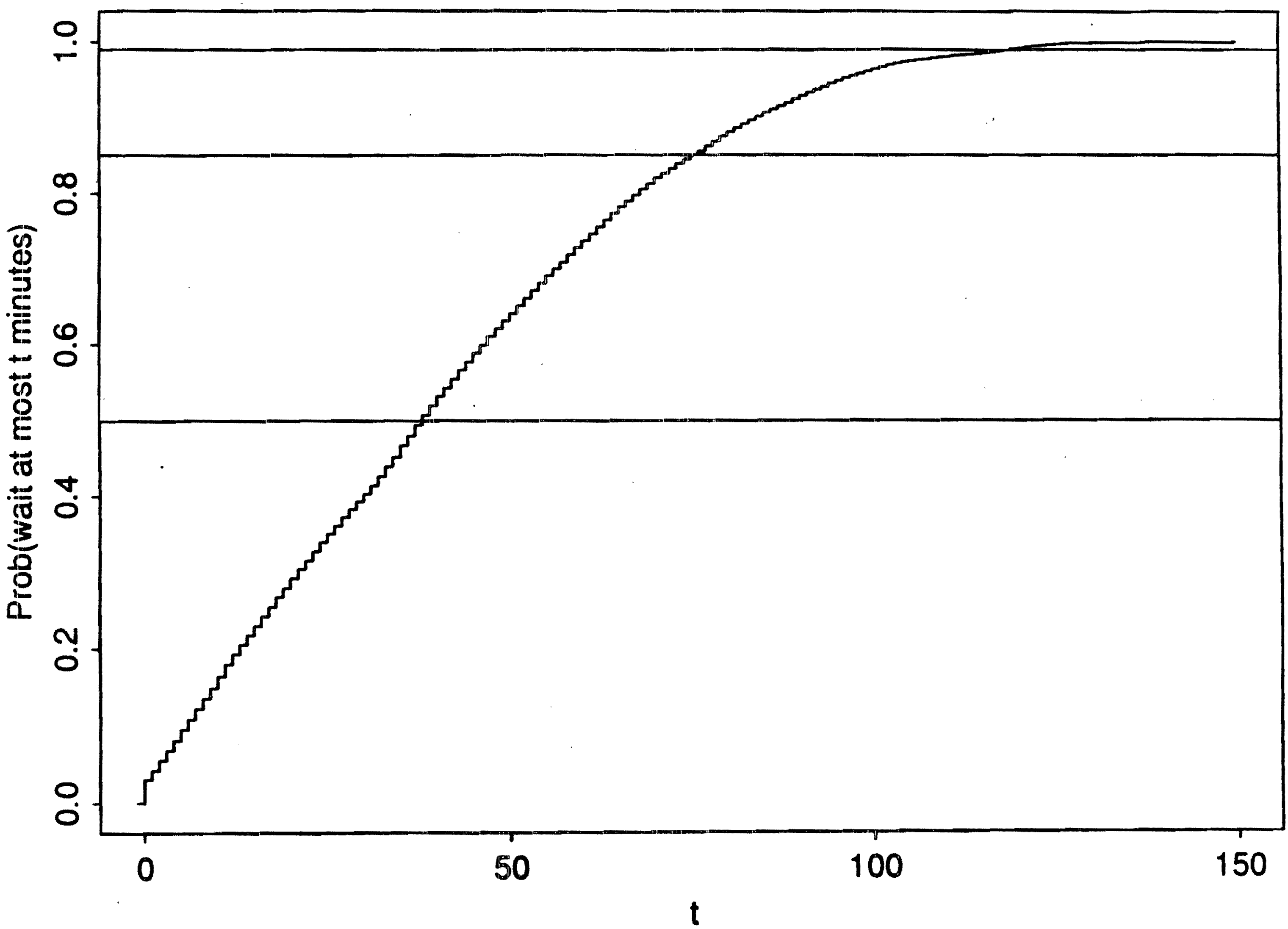
Scenario 4

FIGURE 4: Envirotest Adjusted Extreme Peak Day



Scenario 5

FIGURE 5: MARTA Adjusted Extreme Peak Day



Scenario 6

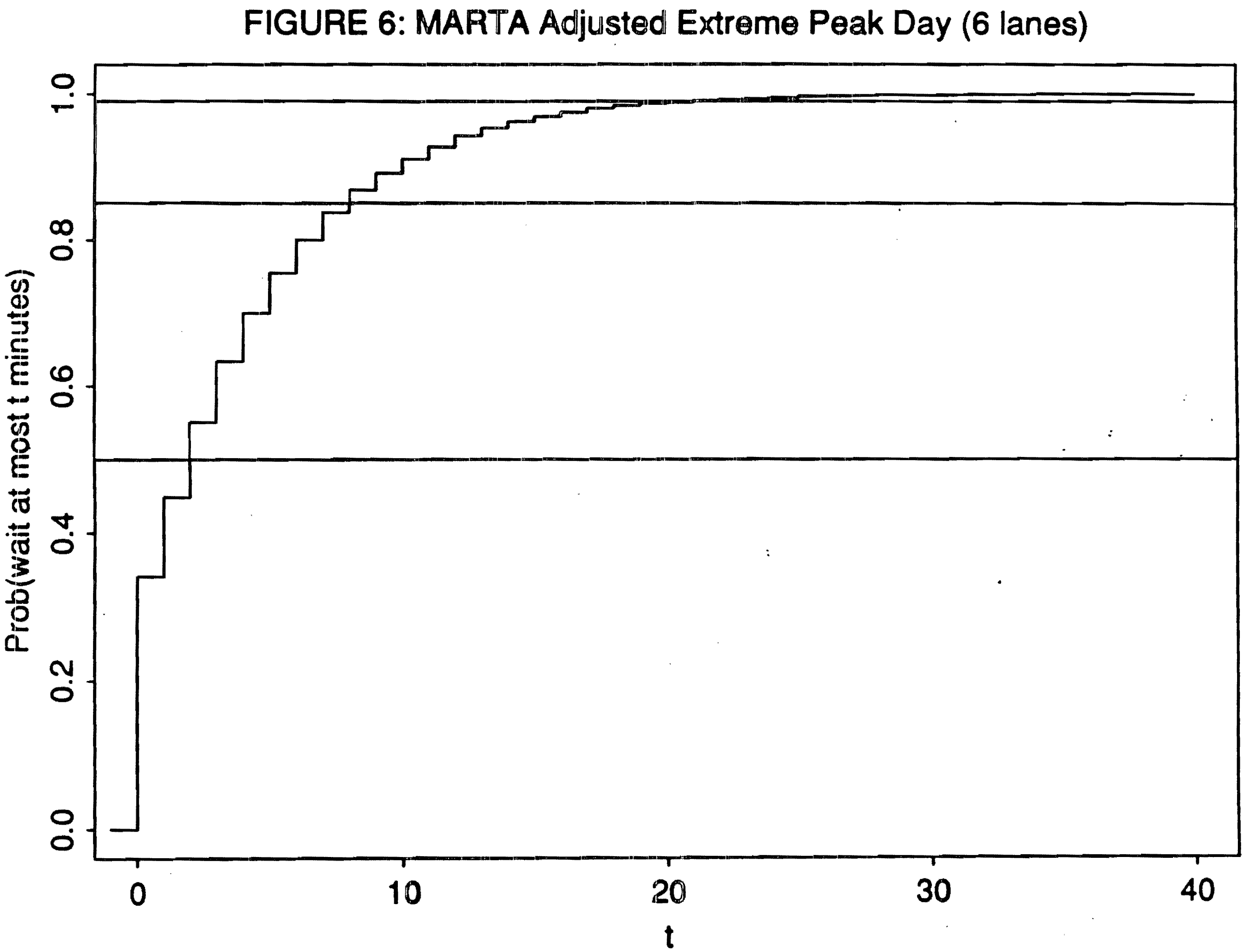


FIGURE 6: MARTA Adjusted Extreme Peak Day (6 lanes)
Prob(wait at most t minutes)
0.0
0.2
0.4
0.6
0.8
1.0
0
10
20
30
40
t

Scenario 7

FIGURE 7: Envirotest Adjusted Extreme Peak 9-hour Day